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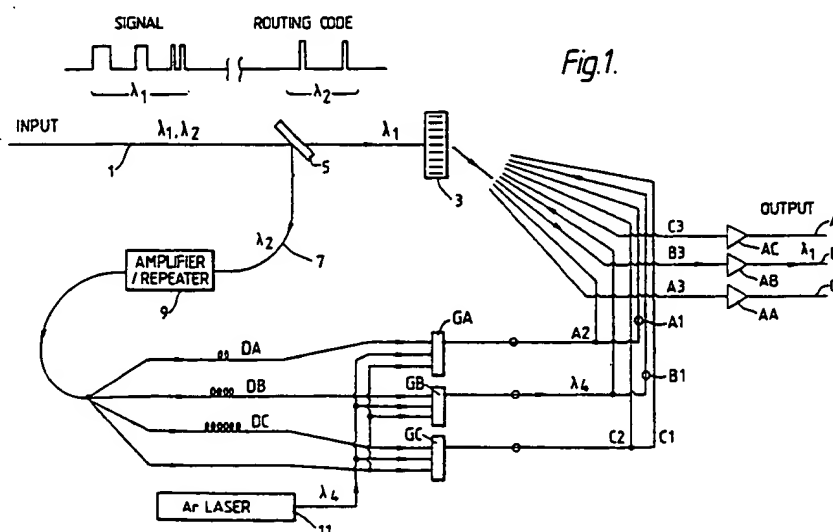The General Electric Company p.l.c.

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(54) Optical routing systems

(57) An optical routing system incorporates a single crystal of bismuth silicon oxide (3), and means for directing first and second light beams onto the crystal so as to encode an incoming optical data signal incident on the crystal towards a chosen one of a number of alternative output channels (A,B,C). The system includes a number of optical logic gates (GA, GB, GC) effective to change the angle of incidence on the crystal of the first and second beams dependent on an optical routing code signal transmitted through a system of optical fibre delay lines onto the gates (GA, GB, GC) so as to change the grating structure and thereby change which of the output channels the data signal is deflected towards.
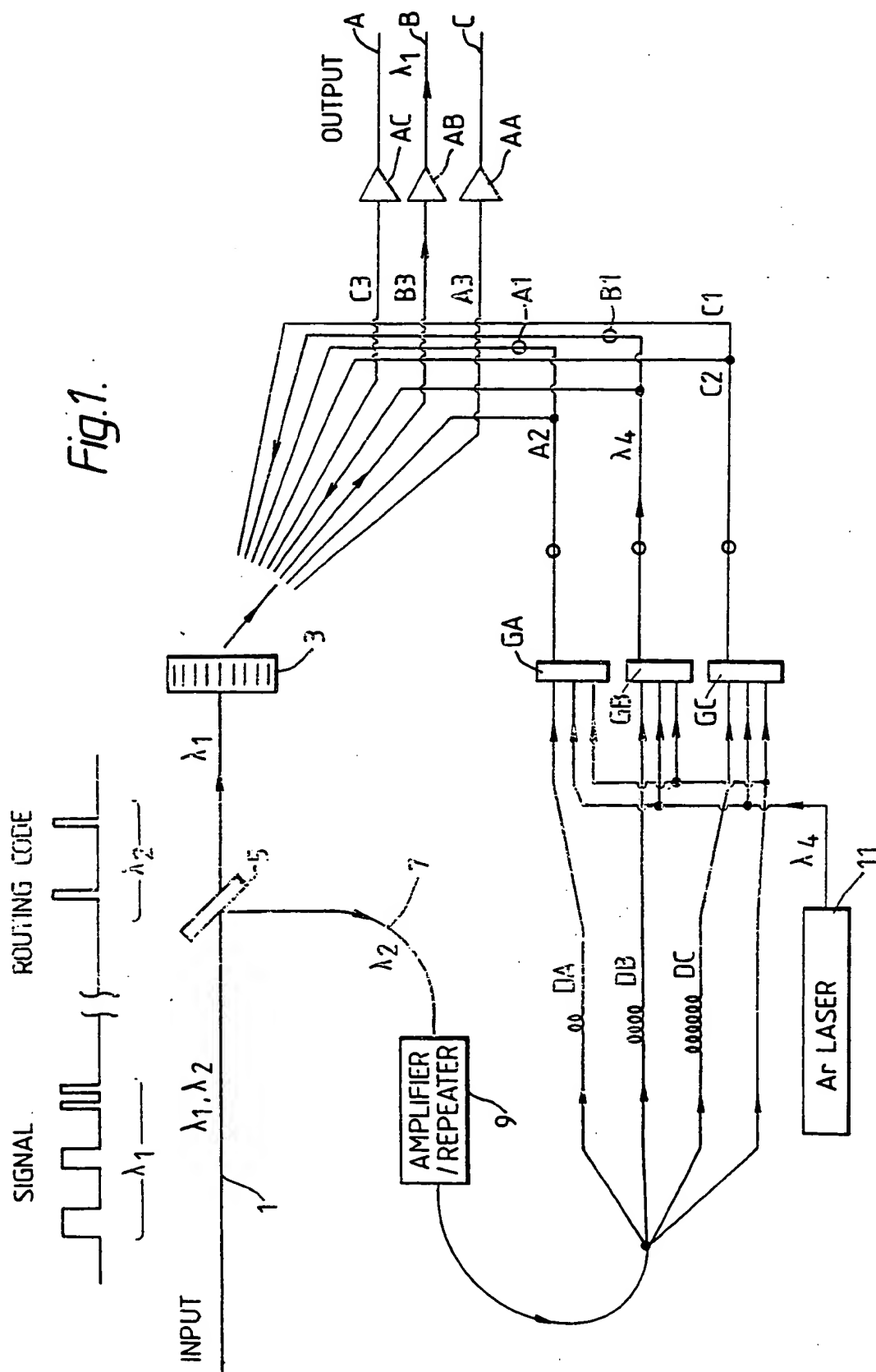

Fig.1.

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Fig.1.

Fig.2.

TIME OF ARRIVAL
OF ROUTING CODE
PULSES AT GATES
GA, GB, GC.

VIA UNDELAYED
PATH

AT GA
VIA DA $\vdash\!\Delta_{\overline{A}}\!\!\rceil$

AT GB
VIA DB $\longleftarrow\Delta_{\overline{B}}\!\rightarrow$

AT GC
VIA DC $\vdash\!\!-\Delta_{\overline{C}}\longrightarrow$

TIME —

Fig.3.

TIME OF ARRIVAL
OF ROUTING CODE
PULSES AT GATES
GA, GB, GC.

VIA UNDELAYED
PATH

AT GA
VIA DA

AT GB
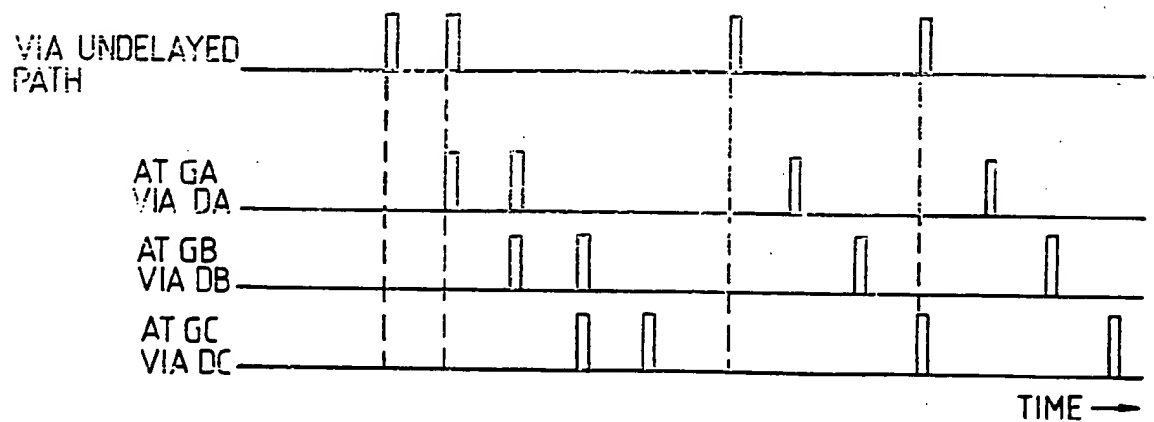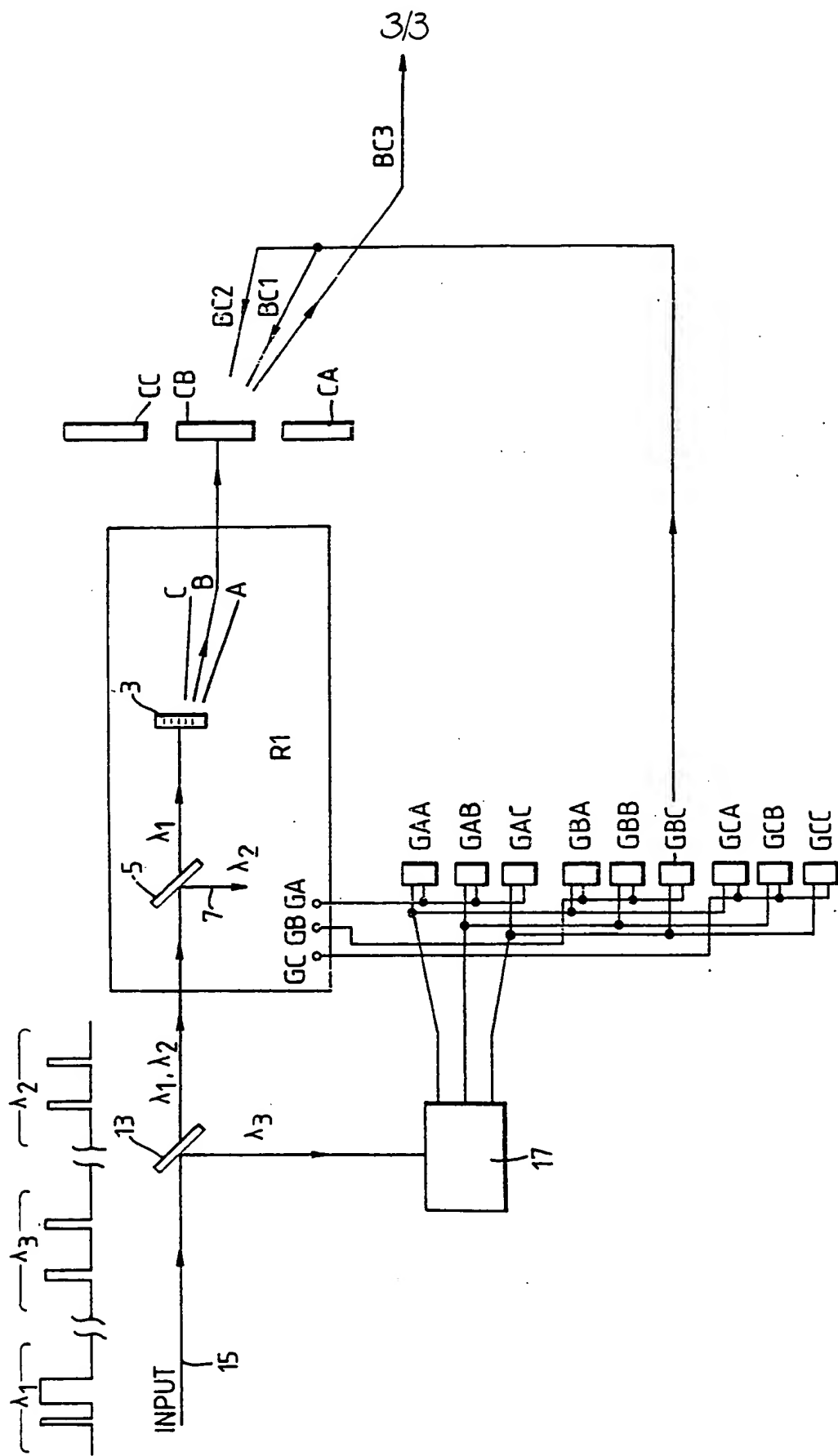VIA DB

AT GC
VIA DC
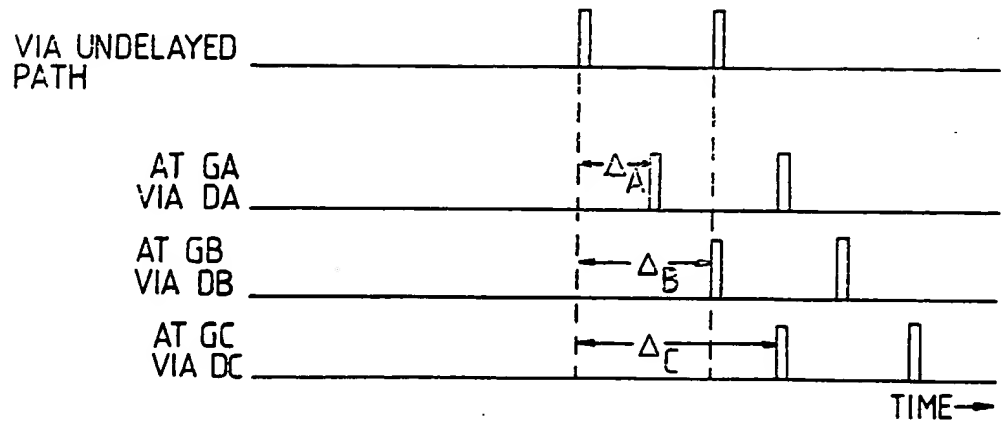
TIME —

Fig.4.

SPECIFICATION

Optical routing system

5   This invention relates to optical routing systems.
Such systems find particular application in optical
communication networks where it is required to route
an incoming optical data signal between two or more
alternative output channels.
10   In the Digest of Technical Papers of the conference
on lasers and electro-optics, held from the 21 — 24
May 1985, in Baltimore, Maryland, there is described
on page 208, Poster Number THM36 one example of a
known optical routing system. The system includes a
15   single crystal of bismuth silicon oxide onto which two
beams of light from a dye laser are directed so as to
encode an effective diffraction grating within the
crystal. The diffraction grating is then used to deflect
an incoming optical signal towards a chosen one of a
20   number of alternative output channels. As the deflec-
tion of the input signal will depend on the period of the
grating which may be varied by variation of the
wavelength of the light produced by the dye laser, the
output signal may be routed between the output
25   channels by applying appropriate control signals to
the dye laser effective to control the wavelength of the
light emitted by the laser.
   Such an optical routing system suffers the dis-
advantage however that the control signals to the dye
30   laser are of the form of either electrical or mechanical
control signals. This will necessarily slow down the
system as it will no longer be a totally optical system.
   It is an object of the present invention to provide an
optical routing system wherein this disadvantage may
35   be avoided.
   According to the present invention an optical
routing system comprising a quantity of an optically
non-linear material, and means for directing first and
second light beams onto the quantity so as to encode
40   an effective grating structure within the quantity, the
grating being effective to deflect an incoming optical
data signal incident on the quantity towards a chosen
one of a plurality of output channels, is characterised
in that the system further includes an optical logic gate
45   means, and means for directing an optical routing
code signal onto the gate means, the gate means
being effective to change the angle of incidence on the
quantity of at least one of the first and second beams
dependent on the routing code signal so as to change
50   the grating structure and thereby change which of the
output channels and the data signal is deflected
towards.
   Preferably the routing code signal is transmitted
down the same communication channel as the data
55   signal, and means are provided for separating the
routing code signal from the data signal. In such a
system the light constituting the routing code signal is
suitably of a different wavelength to that of the data
signal, and the means for separating is a wavelength
60   sensitive optical component.
   The logic gate means suitably comprises a timing
means connected to a plurality of logic gates, each
logic gate being interposed between a coherent light
source and a respective light guide, each light guide
65   being effective to direct light from the coherent light

source onto the quantity at different angles of
incidence, the timing means being responsive to the
routing code signal to select one of the gates to enable
light from the coherent light source to be directed
70   through the light guide connected to the selected gate
so as to produce said first beam.
   Preferably the said second beam is directed from a
second set of respective light guides associated with
each of the gates, light from the coherent light source
75   being split between each pair of light guides associ-
ated with each gate.
   The timing means suitably comprises a plurality of
optical delay lines each arranged to transmit part of
the routing code signal, and each connected to a
80   respective one of the gates, a further transmission
path for the routing code signal being connected to
each of the gates such that when the time period
between different pulses of the routing code signal
corresponds to the time delay across one of the delay
85   lines, the gate connected to the one delay line
provides a light path to its associated light guide.
   Two optical routing systems in accordance with the
invention will now be described, by way of example
only with reference to the accompanying figures in
90   which:
   Figure 1 is a schematic diagram of the first system;
   Figure 2 illustrates a first routing code pulse
sequence;
   Figure 3 illustrates a second routing code pulse
95   sequence; and
   Figure 4 is a schematic diagram of the second
system.
   Referring firstly to Figure 1, the first system to be
described is designed to route an optical data signal
100   transmitted down an input optical fibre 1 between one
of three output optical fibres A, B, C. The fibre 1 is
arranged such that light emitted from the routing
system end of the fibre is incident on a single crystal of
bismuth silicon oxide 3, a narrow band dichroic mirror
105   5 which is designed to transmit light from the fibre 1
within a wavelength band λ1, and reflect light within a
wavelength band λ2 being interposed between the
routing system of the fibre 1 and the crystal 3. An
optical fibre network, indicated as 7, is arranged to
110   collect the light from the fibre 1 which has been
reflected by the mirror 5, pass it through an amplifier/
repeater stage 9, and then divide it into four parallel
paths. The first three paths each incorporate a
respective delay line, DA, DB, DC, and are each
115   connected to a respective optical bistable element GA,
GB, GC of the kind described, for example in Phil.
Trans. R. Soc.Lond. A *313*, pages 195-204 (1984).
These particular elements are arranged to operate as
'AND' gates, the fourth path of the four parallel paths
120   being connected to each gate GA, GB, GC, an argon
laser 11 also being arranged to direct light onto each of
the gates, light from the laser being effective to bias
the gates such that they are subsequently triggered by
a combination of two low intensity incoherent light
125   pulses. The optical outputs of each gate GA, GB, GC,
are arranged to be split into respective pairs of optical
fibres A1 and A2, B1 and B2 and C1 and C2. The ends of
these fibres are arranged round the crystal 3 such that
light passing through the gates GA, GB, GC and
130   subsequently through the fibres A1, A2, B1, B2, C1 and

C2 will strike the crystal 3 at different angles of incidence. Three further fibres A3, B3, C3 whose function is described hereafter are also arranged round the crystal 3, these latter fibres being connected
5 via respective light amplifiers AA, BA, CA to the output optical fibres A, B, C respectively.

In use of the system an optical routing code comprising a series of pulses of light of wavelength λ2 is transmitted down the input fibre to the routing
10 system, the routing code signal being followed by the optical data signal comprising a further series of pulses of light of wavelength λ1. The mirror 5 directs the routing code signal into the optical fibre network 7, a time delay of $\triangle_A$, $\triangle_B$, and $\triangle_C$ being imposed on the
15 divided portions of the routing code signal as they pass through the respective delay lines DA, DB, DC. Where the time delay imposed by one of the delay lines DA, DB, DC is the same as the time between a pair of pulses of the routing code signal, a light pulse will
20 reach one of the gates GA, GB, GC at the same time as the part of the light pulse of the second of the pair of routing code pulses which has travelled down the fourth parallel path which does not incorporate a delay line. This will then open one of the gates GA, GB,
25 GC allowing coherent light from the laser 11 to pass into the fibres A1, and A2, B1 and B2 or C1 and C2 connected to the open gate, and onto the crystal 3. Light from the two fibres A1 and A2, B1 and B2, or C1 and C2 will interact within the crystal 3 to encode an
30 effective diffraction grating, whose period and orientation within the crystal depends on which pair of fibres the light has passed down and thus the angle of incidence of the light on the crystal 3. A latching mechanism associated with each of the gates GA, GB,
35 GC ensures that the gate which has opened is open long enough for the light beams originating from the laser 11 to encode the grating. The subsequent optical data signal incident on the crystal 3 will then be diffracted by this grating, the ends of the fibres A3, B3,
40 C3 being positioned at angles relative to the crystal 3 determined by the Bragg relationship such that the diffracted beam will enter one of these fibres to be amplified by amplifier AA, AB, or AC for onward transmission through optical fibre A, B or C.

45 Figure 2 shows an example of a routing code signal which causes the gate GB to open such that light from the laser 11 is directed through fibres B1 and B2 onto the crystal, the subsequent data signal then being diffracted into fibre B3 for transmission along output
50 fibre B. As can be seen in this figure the time delay $\triangle_B$ imparted to the portion of a routing code pulse passing through the delay line DB is equal to the time between a successive pair of routing code pulses. Thus the part of the routing code signal for the second
55 of the pair of pulses which has passed through the fourth parallel path not incorporating a delay line will arrive at gate GB at the same time as the part of the first pulse which passed through the delay line DB, hence opening gate GB.

60 Figure 3 shows a further example of a routing code signal in which the undelayed part of the second pulse in the routing code signal sequence arrives at gate GA at the same time as the part of the first pulse which has passed through delay line DA, thus causing gate GA to
65 open. The undelayed part of the fourth pulse in the

sequence then arrives at gate GC at the same time as the part of the third pulse which has passed through delay line DC, this then causing gate GC to also open. Light from the laser 11 will then pass through fibres
70 A1, A2 and C1, C2 to encode two effective gratings within the crystal 3, these diffracting a subsequent data signal partially into fibre A3, and partially into fibre C3.

At the end of an incoming data signal, in order to
75 delete the grating or gratings encoded in the crystal 3 ready for the next incoming data signal, a further gating means (not shown) is used to cause the laser 11 to direct a pulse of light down a further optical fibre (also not shown) effective to wipe out the previously
80 encoded grating or gratings in the crystal 3.

In order to avoid the need for long delay lines, routing code signals employing short coding pulses, for example in the order of 1ns, are used. For routing code signals of peak power 1w, 1nJ pulses are then
85 provided which are sufficient to switch the gates GA, GB, GC. The separation between each sequence of routing code signals, and the data signal to be routed, must however be great than the grating formation time.

90 Referring now to Figure 4, the second optical routing system to be described, incorporates a system as described in relation to Figure 1 nested with a similar system in order to form a more complex system in which a single input signal may be routed
95 between nine different output channels. The system as described in relation to Figure 1 is indicated as R1 in Figure 4 the components of R1 being correspondingly labelled to those of the Figure 1 is indicated as R1 in Figure 4 the components of R1 being correspondingly
100 labelled to those of the Figure 1 system. The system R1 is arranged to route an input signal of light of wavelength λ1 between three outputs channel A, B and C as before, the signal being shown as being directed along channel B in Figure 4. The second
105 system also inlcudes a second dichroic mirror 13 interposed between the routing system end of an input fibre 15 and the system R1 and designed to transmit light from the input fibre 15 within the wavelength bands λ1 and λ2, and reflect light within a
110 third wavelength band λ3. An optical fibre network, indicated as 17 is arranged to collect the light from the fibre 15 which has been reflected by the mirror 13, pass it through an amplifier/repeater stage (not shown), and divide it into three parallel paths each
115 incorporating a respective delay line as in the first system. Each path is connected to three optical bistable elements, GAA, GBA and GCA, GAB, GBB and GCB, and GAC, GBC and GCC repectively. The outputs of the gates GA, GB and GC of the first system R1 are
120 also connected to the gates GAA, GAB, GAC, GBA, GBB, GBC, GCA, GCB, GCC as shown in the figure. In analogous fashion to the first system, the output of each gate GAA, GAB etc. is connected to one end of two optical fibres only two of these fibres BC1, BC2
125 being shown, the other ends of the fibres being arranged round three further crystals of bismuth silicon oxide CA, CB, CC, the ends of the fibres connected to gates GAA, GAB, GAC being arranged round crystal DA, the ends of the fibres connected to
130 gates GBA, GBB, GBC being arranged round crystal

DB, and the ends of the fibres connected to gates GCA, GCB, GCC being arranged round crystal DC. Appropriate output fibres, of which only one BC3 is shown are also arranged round the crystals DA, DB, DC.

5   The mode of operation of the second system is analogous to that of the first system, except that a further routing code signal consisting of pulses of light within the wavelength band λ3 is also transmitted down the input fibre 15. Where the delays produced

10   by the system 17 causes a pulse of light of wavelength λ3 to arrive at one of the gates GAA to GCC at the same time as one of the gates GA, GB, GC is open so as to enable light from the laser within system R1 to inpinge on three of the gates, GAA to GCC, these being GBA,

15   GBB and GBC in the particular example illustrated, one of the gates GAA to GCC, will open to allow light from the laser to be directed down a pair of fibres onto one of the crystals DA, DB, DC, so as to further deflect the signal deflected by the crystal in the first R1, the

20   gate GBC being shown as open in the Figure. Thus the data signal passes firstly through the system R1 to be deflected by the crystal 3 in the first system towards one of the CA, CB, CC crystals CB in the example shown in the figure, the signal then being deflected by

25   the crystal CB into the output channel BC3.

It will be appreciated that whilst in each of the systems described herebefore by way of example three gratings of different period and orientation are producible in each quantity of optically non-linear

30   material, i.e. the bismuth silicon oxide crystals, several tens of gratings of different period and orientation may be produced in each quantity of optically non-linear material. As the diffraction efficiency of each quantity is typically in the order of 1%,

35   in principle a large number of output channels could be fed simultaneously from a single input data signal, appropriate amplifiers and/or repeaters being employed to boost the strengtth of the output signal to that of the original signal.

40   It will be appreciated that whilst single crystals of bismuth silicon oxide are particularly suitable for use in systems in accordance with the invention, other quantities of optically non-linear material may be used in systems in accordance with the invention, for

45   example, single crystals of potassium tantalate-niobate.

CLAIMS

1.   An optical routing system comprising a quantity of an optically non-linear material, and means for

50   directing first and second light beams onto the quantity so as to encode an effective grating structure within the quantity, the grating being effective to deflect an incoming optical data signal incident on the quantity towards a chosen one of a plurality of output

55   channels, characterised in that the system further includes an optical logic gate means, and means for directing an optical routing code signal onto the gate means, the gate means being effective to change the angle of incidence on the quantity of at least one of the

60   first and second beams dependent on the routing code signal so as to change the grating structure and thereby change which of the output channels the data signal is deflected towards.

2.   A system according to Claim 1 in which the

65   routing code signal is transmitted down the same communication channel as the data signal, and means are provided for separating the routing code signal from the data signal.

3.   A system according to Claim 2 in which the light

70   constituting the routing code signal is of a different wavelength to that of the data signal, and the means for separating is a wavelength sensitive optical component.

4.   A system according to any one of the preceding

75   claims in which the logic gate means comprises a timing means connected to a plurality of logic gates, each logic gate being interposed between a coherent light source and a respective light guide, each light guide being effective to direct light from the coherent

80   light source onto the quantity at different angles of incidence, the timing means being responsive to the routing code signal to select one of the gates to enable light from the coherent light source to be directed through the light guide connected to the selected gate

85   so as to produce said first beam.

5.   A system according to Claim 4 in which the second beam is directed from a second set of respective light guides associated with each of the gates, light from the coherent light source being split

90   between each pair of light guides associated with each gate.

6.   A system according to Claim 4 or Claim 5 in which the timing means comprises a plurality of optical delay lines each arranged to transmit part of

95   the routing code signal, and each connected to a respective one of the gates, a further transmission path for the routing code signal being connected to each of the gates such that when the time period between different pulses of the routing code signal

100   corresponds to the time delay across one of the delay lines, the gate connected to the one delay line provides a light path to its associated light guide.

7.   A system according to any one of the preceding claims in which the data signals transmitted through

105   the output channels constitute the incoming optical data signals to a further optical routing system in accordance with any one of the preceding claims.

8.   A system according to any one of the preceding claims in which the quantity of optically non-linear

110   material is a single crystal of bismuth silicon oxide.

9.   An optical routing system substantially as hereinbefore described with reference to the accompanying figures.